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APPLICATION

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TITLE: WIDEBAND ARRAYED WAVEGUIDE GRATING

**INVENTORS: Achintya K. Bhowmik
and Biswajit Sur**

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Prepared by: Timothy Trop, Trop, Pruner & Hu, P.C.
8554 Katy Freeway, Ste. 100, Houston, TX 77024
713/468-8880 [Office], 713/468-8883 [Fax]

WIDEBAND ARRAYED WAVEGUIDE GRATING

Background

This invention relates generally to optical filters that may be useful for multiplexing and demultiplexing optical signals in wavelength division multiplexed communication networks.

In wavelength division multiplexed optical signals, a plurality of different optical signals, each having a different wavelength, may be multiplexed over the same optical link. At intended destinations, one or more of the wavelength signals may be separated using a demultiplexing technique.

An arrayed waveguide grating, also called a phased arrayed waveguide or phaser, works like a diffraction grating. It may be fabricated as a planar structure including input and output waveguides, input and output slab waveguides, and arrayed waveguides. The length of any arrayed waveguide may differ from adjacent waveguides by a constant ΔL.

The input slab waveguide splits the wavelength channels among the arrayed waveguides. Each portion of the input light traveling through the arrayed waveguide includes all of the wavelengths that have entered the grating. Each wavelength in turn is individually phase shifted. As a result of that phase shift and phase shifts

at the input/output slab waveguides, every portion of light at a given wavelength acquires different phase shifts. These portions may interfere at the output slab waveguide, producing a set of maximum light intensities. The direction of each maximum intensity depends on its wavelengths. Thus, each wavelength is directed to an individual output waveguide.

Commercially available arrayed waveguide gratings have Gaussian transmission spectral transfer functions that are easy to manufacture. However, high speed applications usually involve flat or wideband profiles. Currently, such flat spectral shapes may be achieved by introducing a horn taper of various profiles, such as parabolic, exponential, sinc, Y-splitter, and the like, at the free propagation region of the arrayed waveguide grating. However, this approach leads undesirably to higher losses than conventional arrayed waveguide gratings and poses manufacturing challenges since horn tapers are very sensitive to fabrication tolerances.

Thus, there is a need for low loss, wideband or flat top arrayed waveguide gratings.

Brief Description of the Drawings

Figure 1 is top plan view of one embodiment of the present invention;

Figure 2 is an enlarged plan view of a portion of the embodiment shown in Figure 1;

Figure 3 is a calculated plot of transmission versus wavelength for the input to the coupler 22 of Figure 1 in one embodiment;

Figure 4 is a calculated plot of transmission versus wavelength for the output from the coupler 22 shown in Figure 1 in accordance with one embodiment of the present invention; and

Figure 5 is a top plan view of a portion of an alternate embodiment in accordance with one embodiment of the present invention.

Detailed Description

Referring to Figure 1, a planar lightwave circuit 10 may include an arrayed waveguide grating. An input waveguide 12 is coupled to an input slab waveguide 14a. The output waveguides 24 are coupled to an output slab waveguide 14b through a directional coupler 22. A slab waveguide, also called a free propagation region, confines light in one dimension, usually the vertical dimension, and does not significantly confine the light in another dimension, typically the horizontal dimension, such as the plane of the circuit 10.

The directional coupler 22 is coupled to the output slab waveguide 14b through the waveguides 18 and 20. In one embodiment, the directional coupler 22 may be approximately a 3-dB coupler. The waveguide array 16, connecting the slab waveguides 14a and 14b, may include a

plurality of waveguides. The difference in length of the successive waveguides in the array is ΔL.

The arrayed waveguide grating may be a dual channel spacing device with Gaussian transmission spectral profile. Referring to Figure 2, the dual channel spacing device may consist of a primary channel spacing 26 (for example that between the waveguides 18a and 20a) and a secondary channel spacing 28 (that between the waveguides 18a and 18b). An array of directional couplers 22 are integrated with the arrayed waveguide grating to achieve the desired transmission spectral profile. The waveguide separation between the adjacent channel pairs coupled to the same couplers 22, i.e., the spacing between the waveguides 18a and 20a, 18b and 20b, on the output slab waveguide 14b, determines the overall spectral width of the transmission profile of the arrayed waveguide grating. This separation is chosen to be an appropriate fraction of the secondary channel spacing to achieve the desired balance between bandwidth, cross-talk, and insertion loss.

The phase difference between the optical beams entering the directional couplers 22 is controlled by choosing appropriate path length difference between the corresponding output waveguides 18 and 20 of the arrayed waveguide grating. As a result, light exits from the intended output waveguide 24 of the directional coupler 22.

For example, in order to get a flat spectral shape, two successive output waveguides 18 and 20 of the arrayed waveguide grating that are input to the couplers 22, have a length difference equal to approximately $(2m+1)\lambda_c/4n_{eff}$, where m is an integer, λ_c is the average center wavelength, and n_{eff} is the effective refractive index of the two respective waveguides.

Figure 3 shows a calculated plot of transmission versus wavelength. The signals A_1 and A_2, centered on approximately 1554 nanometers, in this case, correspond to the signals from the waveguides 18a and 20a. Similarly, the spectra B_1 and B_2 are the signals from the waveguides 18b and 20b and, likewise, the signals C_1 and C_2 are the signals from the next pair of output waveguides.

The primary channel spacing 26 between the signals A_1 and A_2 determines the width of the resulting signal, shown in Figure 4, from the couplers 22. That is, the signal A is the resultant of the signals A_1 and A_2. Thus, the spacing between the signals A_1 and A_2 determines the width of the signal A. Similarly, the signal B is the resultant of the signals B_1 and B_2 by the coupler 22b.

The secondary channel spacing 28, between the signal A and the signal B, is determined by the spacing between the waveguide 18a and the waveguide 18b. This secondary channel spacing determines the wavelength separation between the

adjacent output channels of the overall integrated multiplexer/demultiplexer device.

Thus, in one embodiment, the first and second waveguides 18, 20 have a primary channel spacing 26 that is about one-quarter the secondary channel spacing between the first and third waveguides 18. In other embodiments, different primary and secondary channel spacings may be desirable, but in a variety of cases, it may be desirable to space the individual waveguides 18, 20 of a pair by a smaller separation than successive waveguides 18 are spaced from one another.

Referring to Figure 4, calculated results from a representative device of the type shown in Figure 1 are presented for the coupler 22 output. The secondary channel spacing 28 of the Gaussian arrayed waveguide grating is 100GHz in this example, whereas the primary spacing between the waveguides 18 and 20, coupled to the coupler 22, is four times smaller, i.e., 25GHz, in this example. As shown in Figure 2, the ability to obtain a flat-top spectral shape of the arrayed waveguide grating by the technique described above is demonstrated. The simulated results indicate only about a 1-dB excess loss compared to the Gaussian arrayed waveguide grating and approximately 40-dB cross-talk.

The engineering of the spectral shape of an arrayed waveguide grating can be implemented by monolithic or

hybrid integration approaches. The arrayed waveguide grating and directional coupler structures may be fabricated on the same chip in the monolithic approach, while they are fabricated separately and later bonded together in the hybrid approach.

Referring to Figure 5, in accordance with another embodiment of the present invention, the slab waveguides 15b may be coupled to a multi-mode interference (MMI) coupler 34 in another embodiment of the present invention. In this embodiment, the MMI coupler 34 replaces the directional coupler 22. In this embodiment, the output waveguides 30 and 32 need not be of different lengths. However, the primary and secondary channel spacings may be as described previously in accordance with the embodiment shown in Figure 2. As before, the coupler 34 may be coupled to an output waveguide 36.

While the present invention has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

What is claimed is: